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IOT Based Water Quality Monitoring System

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Abstract

Since the water pollution is increasing globally so implementation of water quality monitoring is effective and efficient with increasing in the development of wireless sensor network (WSN) technology in the internet of things (IOT) environment. Water quality monitoring is remotely monitoring by real time data acquisition, transmission and processing. This paper present reconfigurable sensor interface device for monitoring water quality system with IOT environment for the developing smart water quality monitoring system (SWQM). We are using field programmable array (FPGA) design board, sensors, *zigbee* base wireless communication module and personal computer. The FPGA board is the core component of the developing system and it is programmed with VHDL (very high speed integrated circuit hardware description language) with using quartus – II software and Q sys tool by using C language. We are considering the six parameter of water data like water pH, water level, turbidity, humidity, carbondioxide (CO_2) on the surface of water and water temperature in parallel real time bases with high speed from multiple different sensors nodes.

Keywords- *wireless sensor network (WSN); zigbee, water parameter, internet of things (IOT).*

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1. Introduction

Humans personal task and professional daily tasks, wireless communication technology and wireless sensor network (WSN) [1] are rapidly increasing their contribution with application like data acquisition, building control, environment monitoring system and manufacturing process in the recent years, in the art of wireless sensor network the low cost, easy installation and maintenance with higher operating time the remote sensor network can be used for stationary or mobile sensor network. Generally WSN are using the environmental monitoring, surveying the city development, telemedicine, remote health care, research in agriculture, farming traffic management, border security, fishing surveillance, forest management and disaster prevention. [2]. for the connectivity, embedded computing, signal processing and the sensing, the dispersed sensors nodes are using in the wireless sensor network (WSN) [3]. Propose system are interact between persons or computers and the surrounding environment with wireless link. [4]. Generally the wireless sensing network (WSN) are used in heavy industrial and military application but today's wireless sensing network are use for different purpose in light industrial to heavy industrial systems. The WSN's system are used to monitor and control the connected devices from

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the base station through different wireless communication standard like Wi-Fi, Bluetooth, zigbee, RFID (Radio frequency identification), General packet radio service (GPRS) and cellular technology. [5]. Users can monitor data through wireless network which are designed for wireless communication standards.

The WSN are very efficient for the low power consumption, remote monitoring, data acquisition, fast network setup, wide coverage area, and high monitoring precision and low duty cycle. So the WSN are very powerful equipment to the real word is practically unlimited from the physical security, environmental monitoring and climate changing, positioning and tracking, health care to logistics, localization and so on [6]. The internet of things (IOT) is physical network which connect all the things to exchange the data and information with the help of data sensing devices such as sensors, actuators and computers within line with relevant protocols we can say that the many things are connected into network in one or many form. IoT's [7] are achieved the aims of intelligent, tracking and controlling things, identifying and monitoring the location.

There is verity of IOT application like RFID tags sensor technology, mobile technology and other smart technologies [8]. The integration of less expensive and low power consumption sensors in the IOT are the major evolution of the wireless sensor network (WSN) [9]. The people are interact with real world with the help of invisibly embedded sensor network through the WSN network in IOT application with information and communication system [10]. Recently, an environmental monitoring system based on WSN system using different wireless communication standard has attracted intensive interest. Jing [11] designed wireless remote monitoring system for water supply based on GPRS using PIC microcontroller.

The personal computer management software is develop using vc++ 6.0 software platform. Purohit and Gokhale [12] designed a real time water quality measurement system using Intel microcontroller, global system for mobile communication (GSM) module, assorted water quality majoring sensors, analog to digital converter (ADC) and liquid crystal display (LCD). Since microcontroller have more complex architecture, the development time and cost increased due to complexity of the circuit design. Beri [13] design an autonomous real time device to measure the physical and chemical parameters of water such as pH, temperature and turbidity using Arduino Atmega microcontroller and zigbee wireless module. Hsia [14] develop a water meter system and leakage detections base on field programmable Gate array (FPGA) chip to realize a signal generator detection circuit, data encoder and serial port for the transmission of data. The proposed system consists of sensor, analog to digital converter (ADC) and FPGA design board. Chi et al. [15] presented a reconfigurable smart sensor interface device for industrial area of WSN in the IOT environment these interface devices are restricted as they are commonly base on the comparatively complex dedicated electronic boards [16-18].

Vijaykumar and Ramya [19] designed a real time water quality monitoring system in IOT environment. The system consists of several sensors to major water parameters and the raspberry Pi B+ model as a core controller for the WSN environmental monitoring application, the energy consumption is critically issue due to development of WSN based on the IEEE 1451 standard by combining with complex programmable logic device (CPLD) and the application of wireless communication in the IOT environment.

The research should be perform to achieve a broad space for development in the large number of energy constrained sensor nodes in an unmatched environment so the low power, low cost, single cheap fully integrated autonomous system on chip (soc) base wire sensor nodes is required to solved these problems in the propose smart water quality monitoring system (WQM), the water quality monitoring system consists of group of sensors to monitor the parameter such as water level, water temperature, carbon dioxide (CO_2) on the surface of the water, humidity on the surface of water, turbidity of water and water pH value. In the proposed system sensors are detecting the water parameter and the data is computing on the Altera DE – 1 SoC board using very high speed integrated circuit hardware description language (VHDL) programming language and C – codes then the computing data is transmitted wirelessly to the base station where the user

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can monitor the water parameter through zigbee wireless communication module the block diagram of smart WQM system is shown in Figure 1.

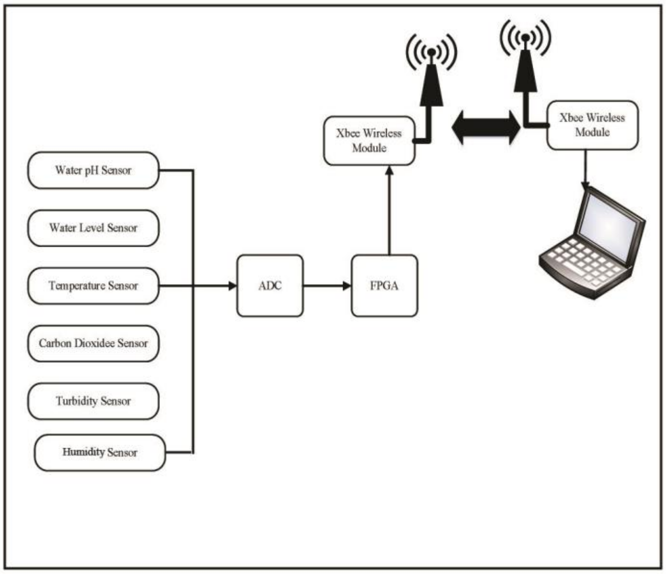

Fig. 1 The block diagram of smart water quality monitoring system

2. Hardware component

In the smart WQM system a reconfigurable smart sensor interface device that integrate data collection, data processing and wireless transmission is design. The hardware design setup is as shown in fig. 2 the wireless water quality monitoring system comprises the following components .

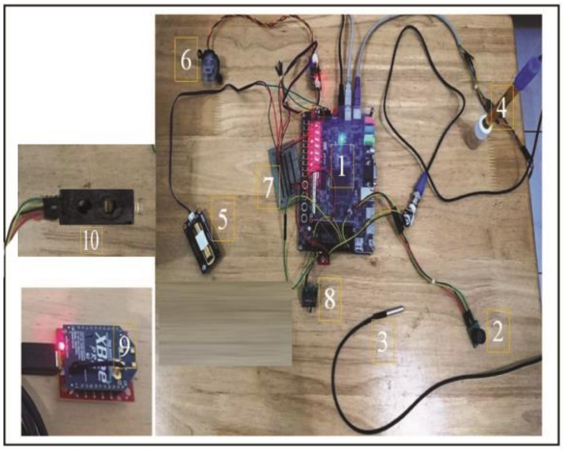

Figure 2: The hardware experimental set-up of smart water quality monitoring system

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- Ultrasonic sensor
- pH sensor
- Digital thermometer sensor
- Humidity sensor
- Turbidity sensor
- CO_2 sensor
- Radio frequency (RF) Module
- FPGA board

A) Ultrasonic sensor

Sensors of this category are considered a good choice being low cost, potential to operate in a variety of applications, and ease of use and adjustability, such as the sampling rate. Common uses are tank monitoring, spray distance measurement (e.g., boom height and width control in order to perform uniform spray coverage, object detection, and collision avoidance). In the propose smart WQM system the ultrasonic sensor (L V Max Sonar - EZI) is chosen to monitor the water level this sensor is operated by emitting high frequency sonic wave at regular time interval starting from the front of the transducer the sonic waves are reflected by an object and received back in the transducer the time interval between emitting and receiving sound wave is proportional distance between transducer and object to be calculated as the ultrasonic sensor is using sound wave instead of light wave it is more suitable for sensing uneven surface such as water surface according to its data sheet object from 0 inches to 254 inches (6.54 meter) and provide sonar range information from 6 inches to 254 inches with 1 inch resolution.

B) pH sensor

In the proposed smart WQM system, the Atlas scientific pH kit is used to detect the pH value of water. The pH kit consists of three main components: EZO TM class embedded pH circuit, BNC shield, and pH probe. In the process of collecting water pH data, the pH probe is connected to BNC shield. The BNC shield transfers the pH probe sensing data to the embedded pH circuit, and the resulted pH data is then provided to the FPGA board. The embedded pH circuit can be operated in two modes. The pH data is converted into binary by the embedded pH such as UART mode and I2C mode. In this proposed smart WQM system, the UART mode is used for its default mode with baud rate of 9600 bps, 8 data bits, 1 stop bit, no parity and no flow control.

C) Digital thermometer sensor

In the proposed smart WQM system, the temperature of the water is monitored using a 1-wire protocol digital thermometer sensor (DS18B20). The DS18B20 temperature sensor provides 9-bit to 12-bit Celsius degree temperature measurements. The DS18B20 is powered from the data line. The range of power supply 3.0V to 5.5V from data line is needed to power the DS18B20. The accuracy of DS18B20 is ±0.5°C from -10°C to +85°C. The temperature is converted 12-bit digital word in a maximum of 750 milliseconds. The temperature sensor DS18B20 is connected to the configurable NiosII soft processor system which is implemented on the Cyclone V FPGA of Altera DE1-SoC board.

D) Humidity sensor

The HIH-5030/5031 Series Low Voltage Humidity Sensors operate on 2.7 Vdc, often ideal in battery-powered systems where the supply is a nominal 3 Vdc. The sensing element's multilayer construction provides excellent resistance to most application hazards such as condensation, dust, dirt, oils and common environmental chemicals. Tape and reel packaging allows for use in high volume pick and place manufacturing (1,000 units per tape and reel), Molded thermoset plastic housing, Near linear voltage output vs %RH, Laser trimmed interchangeability, Low power

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design, Enhanced accuracy, Fast response time, Stable, low drift performance, Chemically resistant and generally we can use for Weather stations and meteorology equipment the humidity sensor working on input voltage supply 2.5 to 5.5 Vdc, the operating temperature of sensor is 40^0C (minimum) to 85^0C (maximum) and operating humidity as minimum 0% RH to maximum 100% RH.

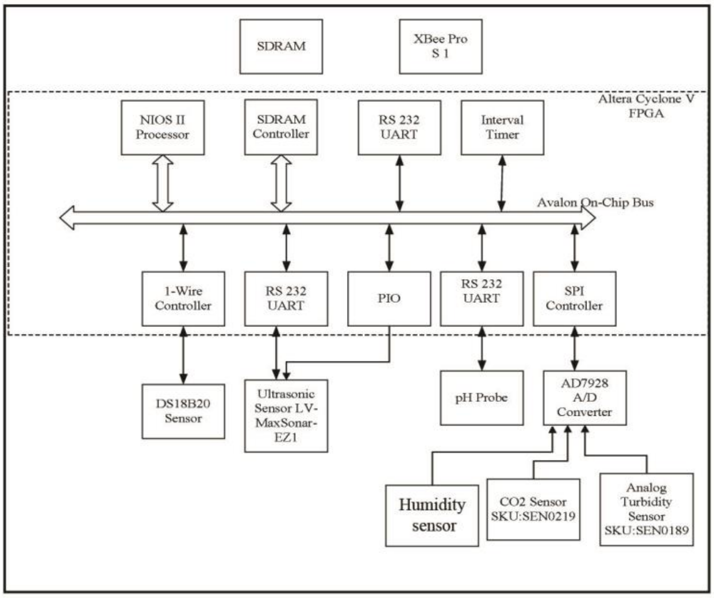

Figure 3: The system block diagram of smart water quality monitoring system

E) Turbidity sensor

In the proposed smart WQM system, the turbidity sensor SKU: SEN0189 is used to detect water quality by measuring level of turbidity. The turbidity sensor enables the detection of suspended particles in water by measuring the light transmittance and analogue and digital signal output modes, either of the mode can be selected according to the microcontroller unit (MCU). The threshold is adjustable by adjusting the potentiometer in digital signal mode. The operating voltage of the turbidity sensor is 5V DC and the operating current is 40mA (max) respectively. According to the reference chart for the mapping from the output voltage to the Nephelometric Turbidity Units (NTU) depending on different temperature, when the sensor is left in the pure water, that is NTU < 0.5, the output should be "4.1±0.3V" when temperature is $10\text{-}50^0$.

F) CO_2 sensor

In the proposed smart WQM system, the Gravity: Analog Infrared CO2 sensor SKU: SEN0219 is used to measure the concentration of CO2. The concentration of CO2 is measured in parts per million (ppm). One ppm is equivalent to 1 milligram of something per liter of water (mg/l) or1 milligram of something per kilogram soil (mg/kg). The characteristics of SEN0219 are waterproof and anti-corrosion, high sensitivity, low power consumption, stability, temperature compensation linear output, high life cycle, anti-water vapour interference and no poisoning. The operating voltage is 4.5-5.5V DC and average current is <60 mA at 5V, the peak current: 150mA at 5V respectively. The effective measuring range of CO2 sensor is 0-5000 ppm. The accuracy of the CO2 sensor is ± (50 ppm + 3% reading).

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G) Radio frequency (RF) Module

XBee multipoint RF modules are ideal for applications requiring low latency and predictable communication timing. Providing quick, robust communication in point-to-point, peer-to-peer, and multipoint/ star configurations, XBee multipoint products enable robust end-point connectivity with ease. Whether deployed as a pure cable replacement for simple serial communication, or as part of a more complex hub-and-spoke network of sensors, XBee multipoint RF modules maximize wireless performance and ease of development. The Zigbee-based WSN systems are simple to install, and very easy to upgrade. The XBee 802.15.4 is a registered brand name of Zigbee Standard which is manufactured by Digi International. The XBee802.15.4 RF modules include Zigbee/Mesh topologies and it can support both 2.4 GHz and 900 MHz frequency. The XBee 802.15.4(IEEE 802.15.4 standard) RF module includes two Embedded-Antenna Module, one XBee USB adapter and one voltage adapter. Since the XBee Series Embedded- Antenna Module pins are not exactly same as the normal pin position, the XBee 5V to 3.3V adapter is required to regulate on a normal breadboard or printed circuit board. The XBee USB adapter performs as a connector between the XBee modules and the monitoring device. The voltage adapter converts the 5V to 3.3V under which the XBee Series Embedded-Antenna Modules is operated. The proper configuration is needed before setting up a wireless communication between the monitoring system and the FPGA board. The two XBee Series Embedded-Antenna Modules are the key components to create the wireless communication between the monitoring device and the FPGA board that operates in universal asynchronous receiver/transmitter (UART) mode.

H) FPGA board

The Altera DE1-SoC board is utilised to control the entire system of the proposed smart WQM system. The DE1-SoC development board includes 85K programmable logic elements, 4,450Kbits embedded memory, 6 fractional phase locked loop **(**PLLs) and 2 hard memory controllers. For communication, two port USB 2.0 Host, UART to USB (USB Mini-B connector), 10/100/1000 Ethernet, PS/2 mouse/keyboard, IR emitter/receiver, and I2Cmultiplexer are provided. The display of the DE1-SoC board is 24-bit video graphics array (VGA) digital-to-analogue converter (DAC). The power supply of 12V direct current (DC) is needed to power the board. The total resource utilisation to design the FPGA board of the proposed smart WQM system is as **FPGA Resource Utilisation** Logic utilization (in ALMs) 1,724 / 32,070 (5%), Total registers 2662, Total pins 149 / 457 (33 %), Total block memory bits 83,072 / 4,065,280 (2 %), Total PLLs 1 / 6 (17 %), Max Clock Frequency 58.75 MHz.

3. SYSTEM ARCHITECTURE

The system block diagram of smart WQM system is shown in Fig. 3. This architecture is used for the entire system of the Cyclone V DE1-SoC FPGA board due to the significant flexibility to deal with a trade off between processing and communication. The sensor nodes are stationed at the bank of the water. The measured data of water parameter are collected by the sensor nodes and sent to FPGA board. The analogue output of CO_2 sensor, humidity sensor and Turbidity sensor are digitized by AD7928 Analog to Digital converter. The Ultrasonic sensor and pH sensor are interfaced with RS232 and the default state is UART mode which acts as the transmission (TX) line. The default baud rate is 9600, 8 bits, no parity, no flow control and one stop bit. The temperature sensor DS18B20 communicates over a 1-wire bus which requires only one data line (and ground) for communication with a microcontroller. Serial Peripheral Interface (SPI) bus is used in embedded system to communicate the microprocessor to off-chip sensors, conversion, memory, and control devices. The architecture of SPI is designed for connecting on-chip

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processors and peripherals together into a system-on-a-programmable chip (SOPC). When the transmitted data from sensor nodes are received by the gateways, SPI transfers the incoming data through the UART interface to the processor. The SPI controller performs nRF24L01 module initialization, receives and sends packets. The Avalon bus is an interface protocol that is designed to connect on-chip processors and peripherals together into the SOPC.

The Avalon bus specifies the port connections between master and slave components, and specifies the timing by which these components communicate. The Nios II processor is connected to its embedded peripherals such as parallel input/output (PIO), SPI, on-chip random access memory (RAM), JTAG UART, Timer, UART (RS232 serial port), synchronous dynamic random access memory (SDRAM) controller by means of the Avalon. The multiple slave devices are attached on the Avalon on-chip bus such as SPI, UART, and general purpose input/output (GPIO) and custom logic. The Nios II processor is a general purpose configurable soft core processor and it includes a 32-bit central processing unit (CPU) and a combination of peripherals and memory on a single chip. The configuration of Nios II selected the Nios II/fast in order to provide the most effective performance to the processing unit. The SDRAM synchronizes itself with the timing of the CPU. Therefore, the memory controller identifies the exact clock cycle when the requested data is ready. The UART is used to connect Nios II processor to the Zigbee hardware for wireless transmission.

4. SOFTWARE DESIGN

Since the Altera Quartus II Software is the primary FPGA development tool, the Altera Quartus II Software and the Nios II Embedded Design Suite (EDS) are chosen to build a hardware system design and create a software program that runs on the Nios II system. This programmable logic device design software is produced by Altera and it is compatible with Altera DE1-SoC design board. To display the wirelessly received data of water parameters on PC, the Pythons codes are used to display on the Grafana. The monitoring PC is operated in Linux mode.

A. Software Program

The software program consists of the C codes running over the embedded Nios II processor within the FPGA processor and VHDL codes as shown in fig. 4 The Quartus II software is used to create VHDL codes of the interfaces, then the compilation is performed and the system is downloaded into the FPGA device. The Nios II is a soft processor and it is implemented in the FPGA device by using the Quartus II CAD system. The Nios II Integrated Development Environment (IDE) is software development environment of Nios II processor and it is based on the GNU C compiler and Eclipse IDE. The Nios II Software Build Tools (SBT) is used for Eclipse™ and all software development tasks are performed in the Nios II processor system. The Nios II system is generated using Qsys to add the desired components, and to configure how the components connect together. The C software application code is created with the Nios II SBT for Eclipse by using information from the ***.sopcinfo*** file which is needed to configure the FPGA before running and debugging the project on target hardware. The software programs for sensor nodes and wireless network are written in C and it is run in NIOS II IDE with the NIOS II processor. Finally, the Nios II system is integrated into the Quartus II project. Later, the final FPGA hardware design is created by using the Quartus II software.

B. Flow Chart

When the smart WQM system is switched on, the data from each sensor node is collected one after another using time multiplexing. Then, the data of all of 6 sensors is converted to 8 bits binary. The collected data is stored in the integrated SRAM on the interface device. The accumulated data is transmitted to XBee transmitter module in terms of data transmission. The flow chart of the wireless water quality monitoring system is shown in Fig.5. The results of 6

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parameters of water quality are displayed on the Grafana which is installed in PC to visualize time series data using the Python codes.

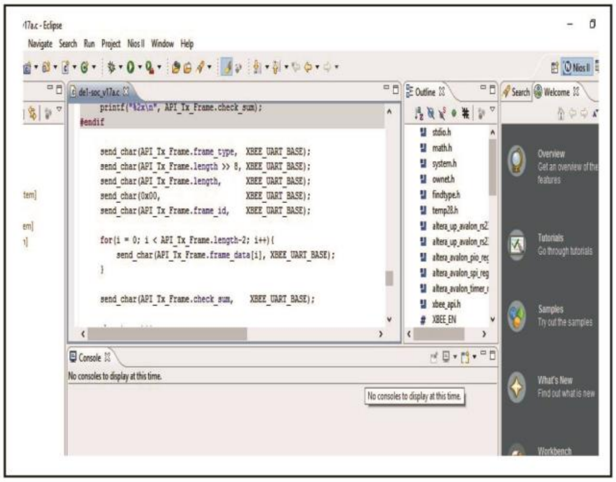

Figure 4: A part of C codes to transmit and receive water parameters wirelessly through XBee module

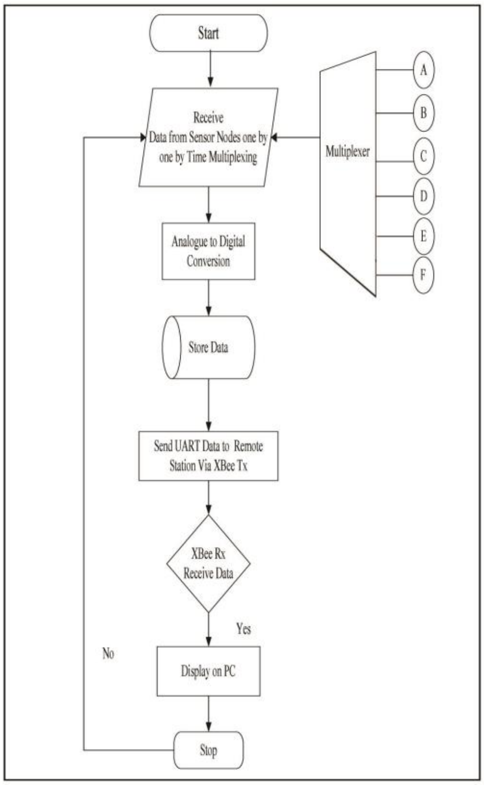

Figure 5. The flow chart of software smart water quality monitoring system

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TABLE 1. Reading of Water Parameter

Readings on the Grafana				
Water Parameters	**Min.**	**Max.**	**Average**	**Current**
Temperature	30^{0}C	54^{0}C	40^{0}C	44^{0}C
Water Level	352	353 1.570 m	551	552 1.570 m
pH	12	12	12	12
CO_2	690 ppm	1071 ppm	765 ppm	714 m
Turbidity	3	3	3	3
Humidity	14% RH	18% RH	16% RH	15% RH

5. RESULTS AND DISCUSSIONS

In the smart WQM system, when the sensor board is switched on, the sensors are activated to detect the individual water parameter data. Then, the collected water parameters are transmitted wirelessly to monitoring device which is PC using Nios II software program in the Altera Quartus II software. The data of water level, humidity, pH, turbidity, carbon dioxide and temperature are displayed on the Grafana dashboard on the PC using Python codes. The results of water parameters are displayed on the Grafana dashboard as shown in Fig. 6. The reading of water level is changed when the distance between water surface and water level sensor is changed. The readings of water temperature vary according to the increasing and decreasing of the water temperature by using warm water and ice water. The range of the value is displayed for the monitoring of pH, temperature, humidity, turbidity, carbon dioxide and level of water. The readings of the experimental result of water quality monitoring system are shown in Table. 1. The data is being monitored continuously and displayed in real time since the default of the system is set in continuous mode. The interval of the sensing time is selected for 1 hour and the data is refreshed every 5s. The proposed smart WQM system reduces power consumption, which outperforms the performance of the conventional microcontrollers-based WSN. Recently, IoET, Cloud based, RF sensor based technology is getting popular due to their inherent characteristics such as low cost solutions, reliability and scalability, accuracy in detention and precise operation[20-24]. In future, the proposed systems and concept can be implemented with these concepts.

Figure 6: The experimental result of smart water quality monitoring system shown of Grafana

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6. CONCLUSIONS

The proposed smart WQM system of single chip solution to interface transducers to sensor network using FPGA is presented with wireless method by using a wireless XBee module. The results of the six parameters of water quality are verified that the system achieved the reliability and feasibility of using it for the actual monitoring purposes. All states have established specific criteria identifying what concentration of pollutants are allowable in their water when chemical pollutants exceed maximum allowable concentration water might no longer be able to support the beneficial uses such as fishing, swimming and drinking for which they have been designated. The water temperature may vary from 0 to 0.4 Degree Celsius depending on the speed of the ambient air temperature cycles. The time interval of monitoring can be changed depending on the need. By introducing the FPGA board, the proposed system inherits high execution speed and reusable Intellectual Property (IP) design. The proposed system will assist in protecting the ecological environment of water resources. The smart WQM system minimizes the time and costs in detecting water quality of a reservoir as part of the environmental management. The WSN network will be developed in the future comprising of more number of nodes to extend the coverage range.

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